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REMNANT FIELDS IN THE MAIN RING BENDING MAGNETS

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A variety of correction magnets are distributed about the main ring to compensate for imperfections in the main-ring magnets. The amount of correction needed is dependent to a large extent on the remnant fields in the bending magnets. To determine the extent to which the remnant fields dominate the injection field errors, a series of measurements have been made on the bending magnets located in the transfer hall magnet cage using a Rawson probe, Model No. 944M42, mounted on a micrometer-driven stage.

Measuring magnets in the cage provides an advantage over separate magnets in that they have experienced the same history as the magnets in the ring as far as ramping is concerned.

B1 — REMNANT FIELDS

The B1 was first measured after normal 300-GeV ramping, and turning off the power supply during front porch. As can be seen from Figure 1, the gradient of the remnant field when plotted as a function of radius is an S-shaped curve with the central region being nearly pure sextupole while in the outer regions the gradient increases more slowly than a sextupole field does. The slope of the central sextupole region is .463 gauss/in^2. These measurements were made at approximately 24", 23", and 20" inside of the magnet, moving the probe in .100-inch steps across the vacuum chamber.

Following this the magnets were ramped to 100 GeV, the power supply was turned off during front porch and the remnant fields were measured. As can be seen from Figure 1, no change in the B1 remnant field was seen when going from a 300-GeV ramp to a 100-GeV ramp.

Figure 2 shows the B1 remnant field changes substantially in going from a 300-GeV ramp to a 400-GeV ramp. The same basic S shape was maintained, but the gradient is reduced by nearly 25% giving a slope in the central region of .355 gauss/in^2 at 400 GeV compared to the .463 gauss/in^2 at 300 GeV. As before, the ramp was turned off during front porch after normal 400 GeV ramping.

The 400 GeV B1 remnant field was also measured after tripping the ramp at flattop. This allows the current to decay more slowly and allows one to see what effect invert has on the remnant fields. The remnant field was measured at the same location under the two different turn-off procedures and the slow turn off was found to produce an even smaller gradient as can be seen in Figure 3.

B2 - REMNANT FIELDS

Figure 4 shows the remnant fields of the B2 magnet. As in the case of the B1 the plot of gradient vs. radius is an S-shaped curve; the slope of the central region is .443 gauss/in^2. These measurements were made after 300-GeV operation was interrupted by a feeder failure.

The B2 was also measured following 400-GeV ramping and in contrast to the B1 very little change in the remnant fields was measured. As can be seen in Figure 5 the slope is reduced by approximately 5% to .408 gauss/in^2.

SEXTUPOLES

Correction sextupoles can be used to compensate for the remnant fields in the central region of the bending magnets, but such compensation results in overcorrection at larger radii. Since the sextupole correction fields are too strong away from the central region it is desirable to either add correction elements such as decapoles or distort the sextupoles to remove the overcorrection. The sextupole field can be decreased at large radii without significant change in the central region by inserting plastic spacers in the correction magnet. Such spacers produce a field gradient which when plotted vs. radius is S shaped.

Figure 6 is the graph of the field gradient vs. radius of a correction sextupole with no spacer. The slope of the gradient is 37.0 gauss/in^2 amp. Inserting a 1/4-inch spacer reduces the slope to 29.25 gauss/in^2 amp and as can be seen in Figure 7, adds a negative decapole and higher order moment to the field. Figures 8 - 11 show the effect of increasing the spacers in 1/4-inch steps from 1/2 inch to 1-1/4 inches. As the gap is increased the slope of the central sextupole gradient decreases and an increasing higher order negative multi-pole is added to the field.

These measurements allow one to find the proper sextupole spacers and current to compensate for the remnant fields in the bending magnets.

B1 CORRECTIONS

Sextupoles without spacers correct for B1 remnant fields up to a radius of $\sim \pm 1$ inch as is shown in Figure 12. Beyond that radius the fields are greatly overcorrected. Inserting a 3/4 inch spacer - Figure 13, is an improvment, but still provides an overcorrection at large radii. Increasing the gap to 1 inch provides a correction magnet that very closely matches the 300 GeV remnant field and a 1-1/4-inch gap field is not strong enough at large radii as can be seen in Figures 14 and 15.

The horizontal sextupoles used to compensate for the B1 magnets which are located at 84 horizonally focusing locations in the main ring are presently separated with one-inch spacers. As can be seen from Figure 16, a slightly larger gap might be beneficial for operation at 400 GeV.

B2 CORRECTIONS

The vertical sextupoles, of which there are also 84, are located at vertically focusing locations and are used to correct for the B2 field errors. Presently these sextupoles used without spacers and as is shown in Figure 17 the field are compensated for up to a radius of $\sim \pm 7/8$ inch. Figure 18 shows that the insertion of a 1/4-inch gap does not measurably change the correction. This presents a question as to why the insertion of 1/4-inch spacers in the vertical sextupoles, which were removed after less than 24-hours operation, had such a negative effect. One must conclude that perhaps an error in installation such as a ground fault was responsible, and the experiment should be repeated.

Figure 19 shows that a gap slightly larger than 1-1/4 inch is needed in the vertical sextupoles for 400-GeV operation, a similar situation for 300 GeV, to correct for the remnant field in the B2's.

OPERATING CONDITIONS

Knowing the number of sextupoles, 84 horizontal and 84 vertical, the number of B1's - 378, and B2's - 396, their respective lengths - 6 inches and 20 feet, and the fact that the sextupoles are shunted with 39Ω resistors, one can calculate the sextupole currents needed to correct for the remnant fields. The horizontal sextupoles are used to cancel the remnant field gradient in the B1's, however, the vertical sextupoles are usually set to over compensate for the B2's by ∿ 20% to provide a stabilizing tune spread. The super damper will probably remove the need for this tune spread.

Therefore, the operating conditions at 300 GeV are calculated to be as follows:

Sex H - (1-inch gap) I = 4.15 amps
Sex V - (no gap) I = 2.35 amps (with tune spread 2.83 amps)

The vertical sextupoles should be installed with 1-1/4-inch gaps which require a current of:

Sex V - (1-1/4-inch gap) I = 4.67 amps (with tune spread 5.61 amps)

At 400 GeV the currents should be changed to the following:

Sex H - (1-inch gap) I = 3.18 amps
Sex V - (no gap) I = 2.17 amps (with tune spread 2.61 amps)
Corrected Sex V - (1-1/4-inch gap) I = 4.31 amps (with tune spread 5.18 amps)

The calculated 300-GeV operating currents agree well with the present operating currents which are Sex H = 4.2 amps, Sex V = 2.8 amps. This indicates that injection field errors other than those coming from the remnant fields, e.g., end packs, are negligible under 300-GeV ramping conditions.

It is expected that similar results will be experienced at 400 GeV, however, as the magnets are increasingly excited towards saturation the remnant fields and other field errors may change in relative importance.

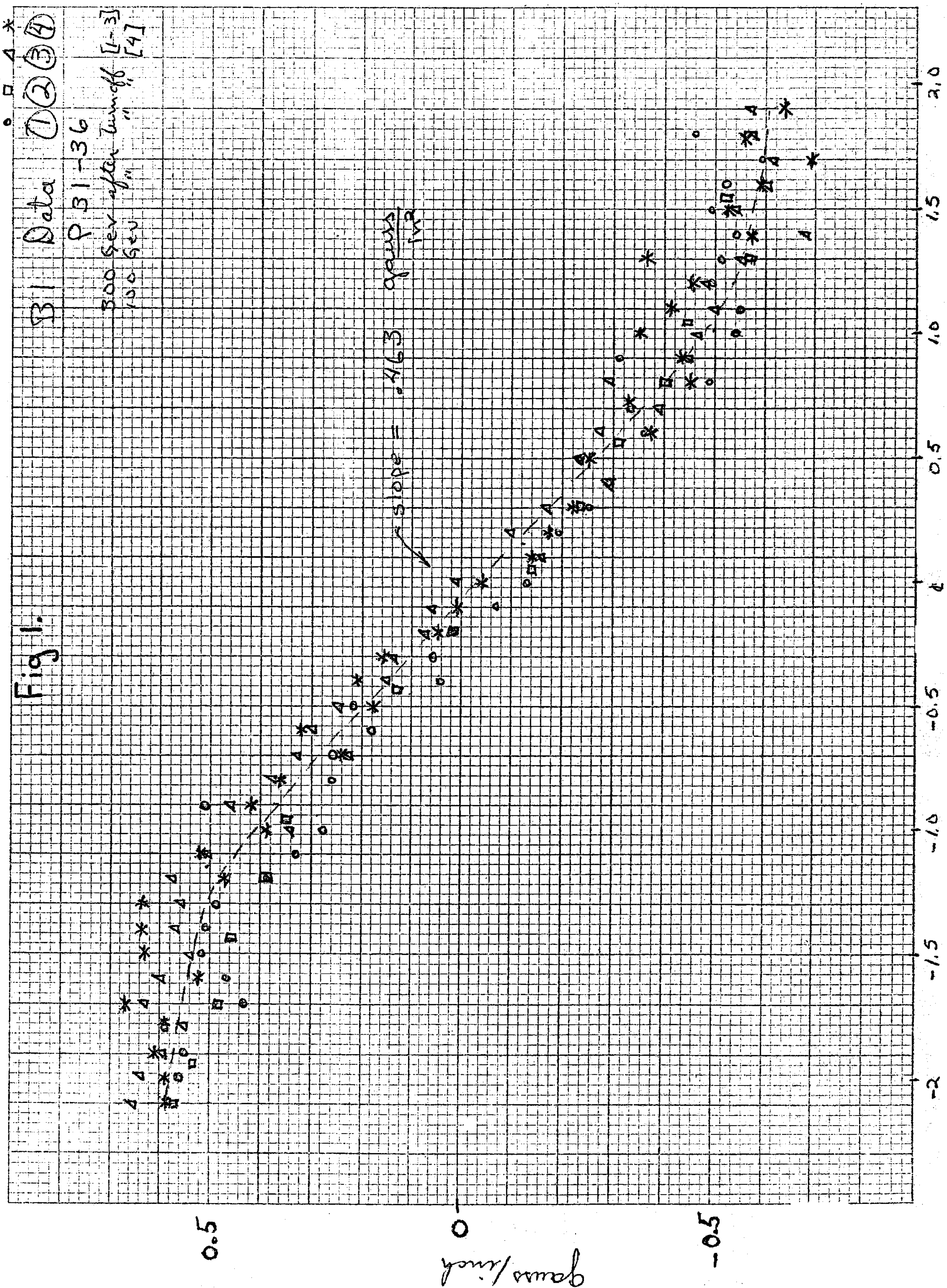


Fig. 1.
B1 Data
① ② ③ ④
P B1-36
300 GeV after turnoff [1-3]
100 GeV " " [4]
slope = .463 gauss/in²
-2
-1.5
-1.0
-0.5
0
0.5
1.0
1.5
2.0
0.5
0
-0.5
gauss/inch

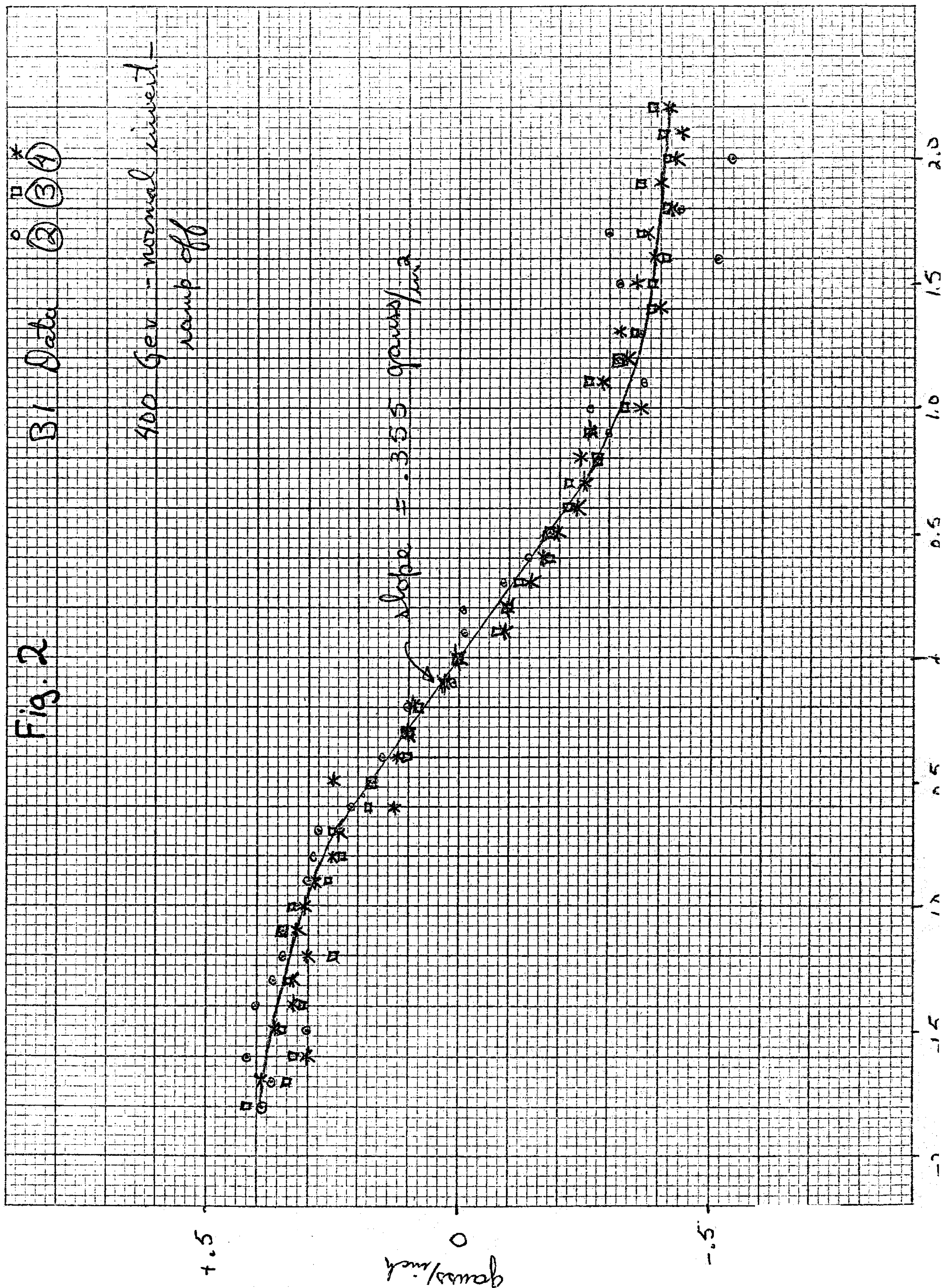


Fig. 2
B1 Data ② ③ ④
400 Gev - normal inverted ramp off
slope = .355 gauss/in²
+.5
0
-.5
gauss/inch
2.0
1.5
1.0
0.5

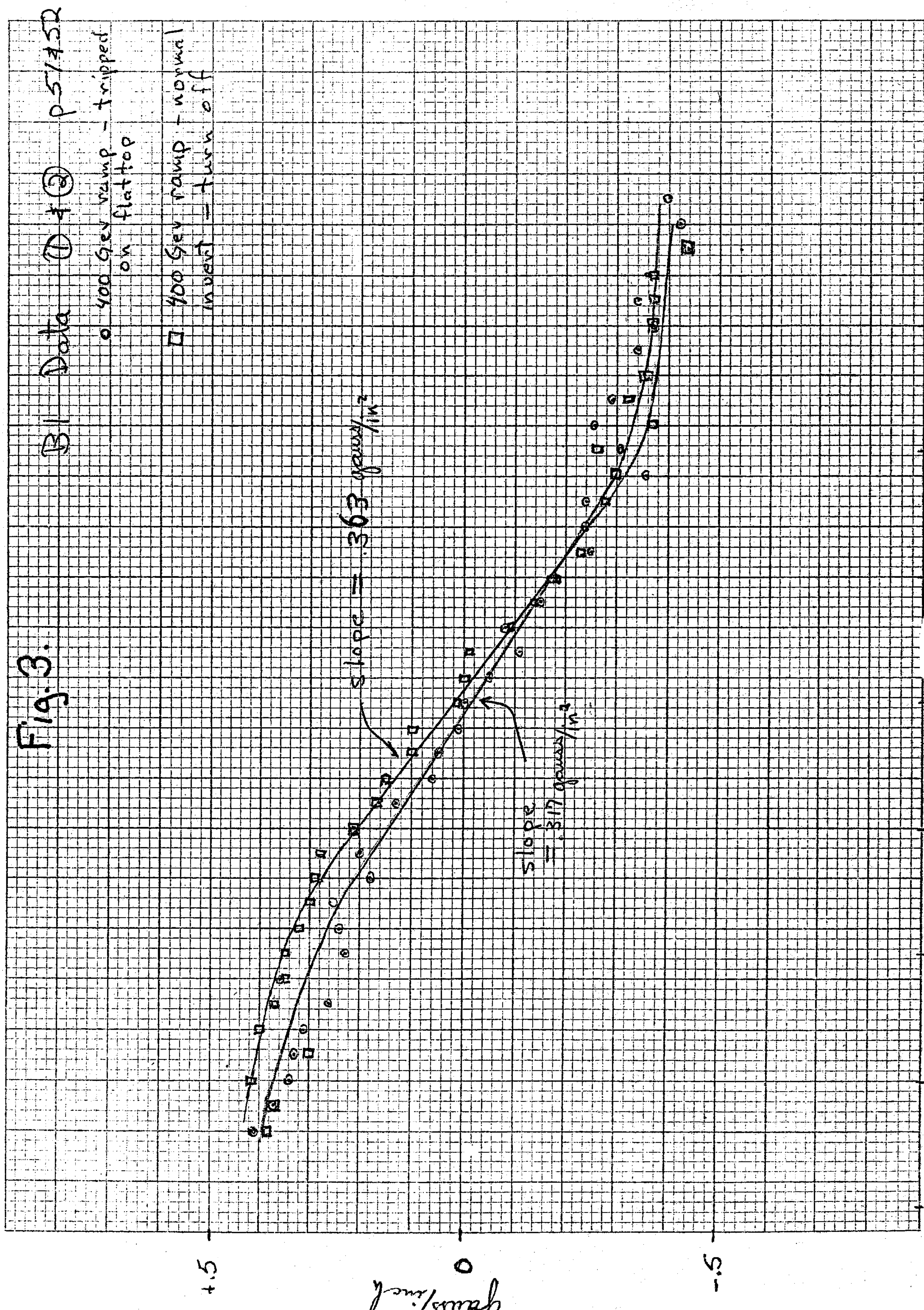
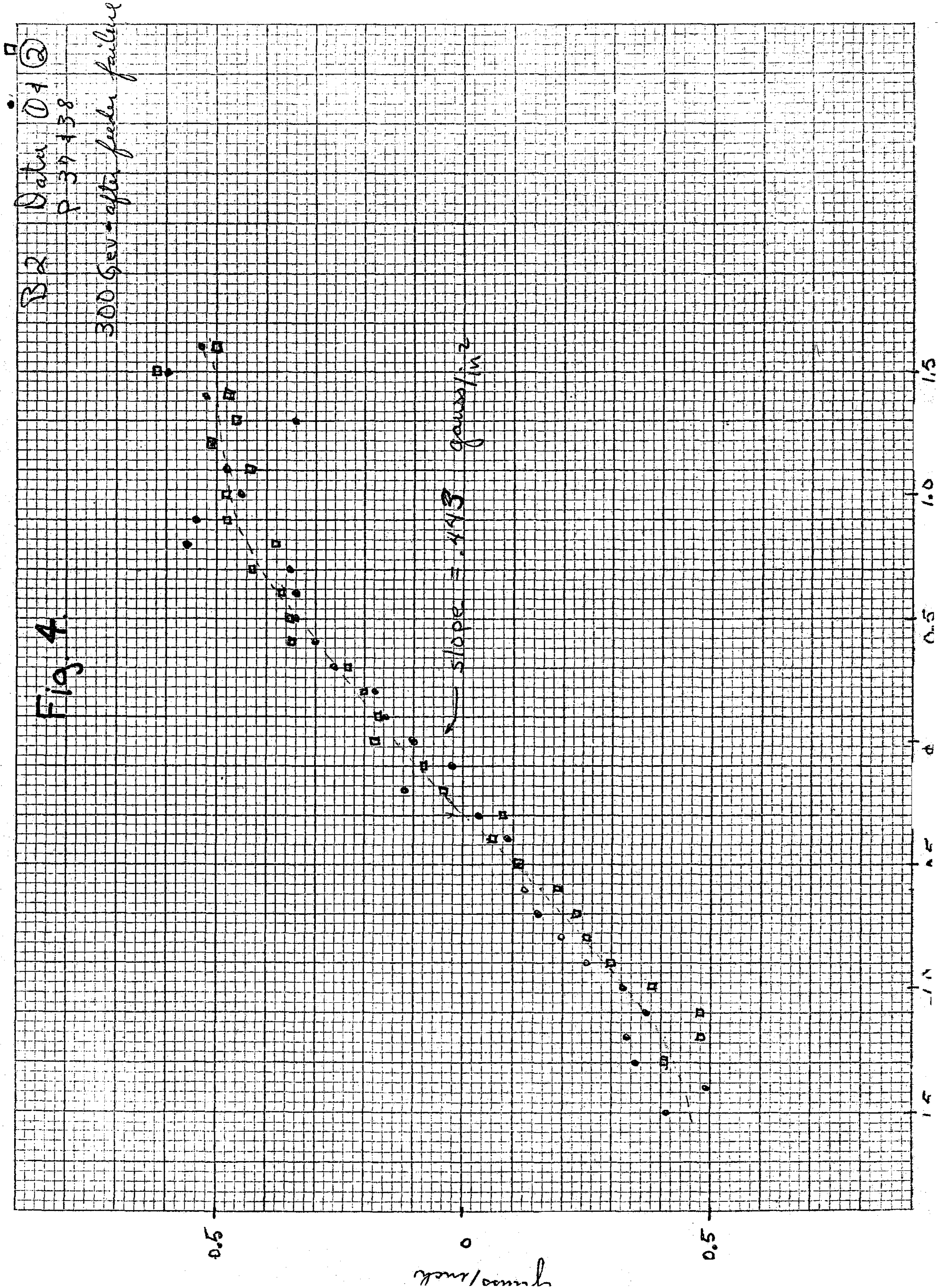


Fig. 3.
B1 Data ① + ② p5/#52
○ 400 Gev ramp - tripped on flattop
□ 400 Gev ramp - normal invert - turn off
slope = .363 gauss/in²
slope = .317 gauss/in²
+.5
0
-.5
gauss/inch
-2.0
-1.5
-1.0
-0.5
℄
0.5
1.0
1.5
2.0


B2 Data ① & ②
P 37 & 38
300 Gev • after feeder failure
Fig. 4.
slope = .443 gauss/in²
1.5
1.0
0.5
0
0.5
0
0.5
gauss/inch

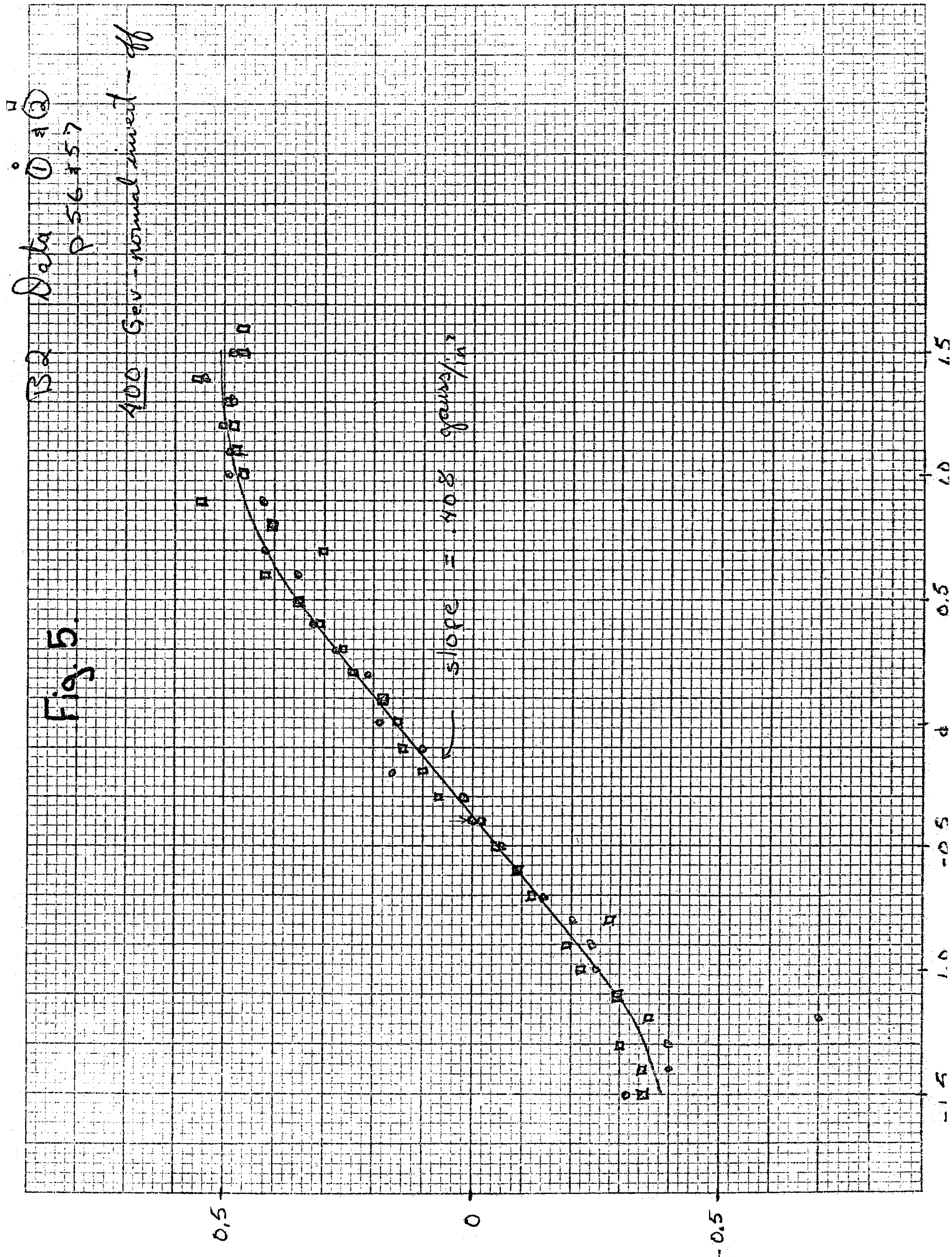
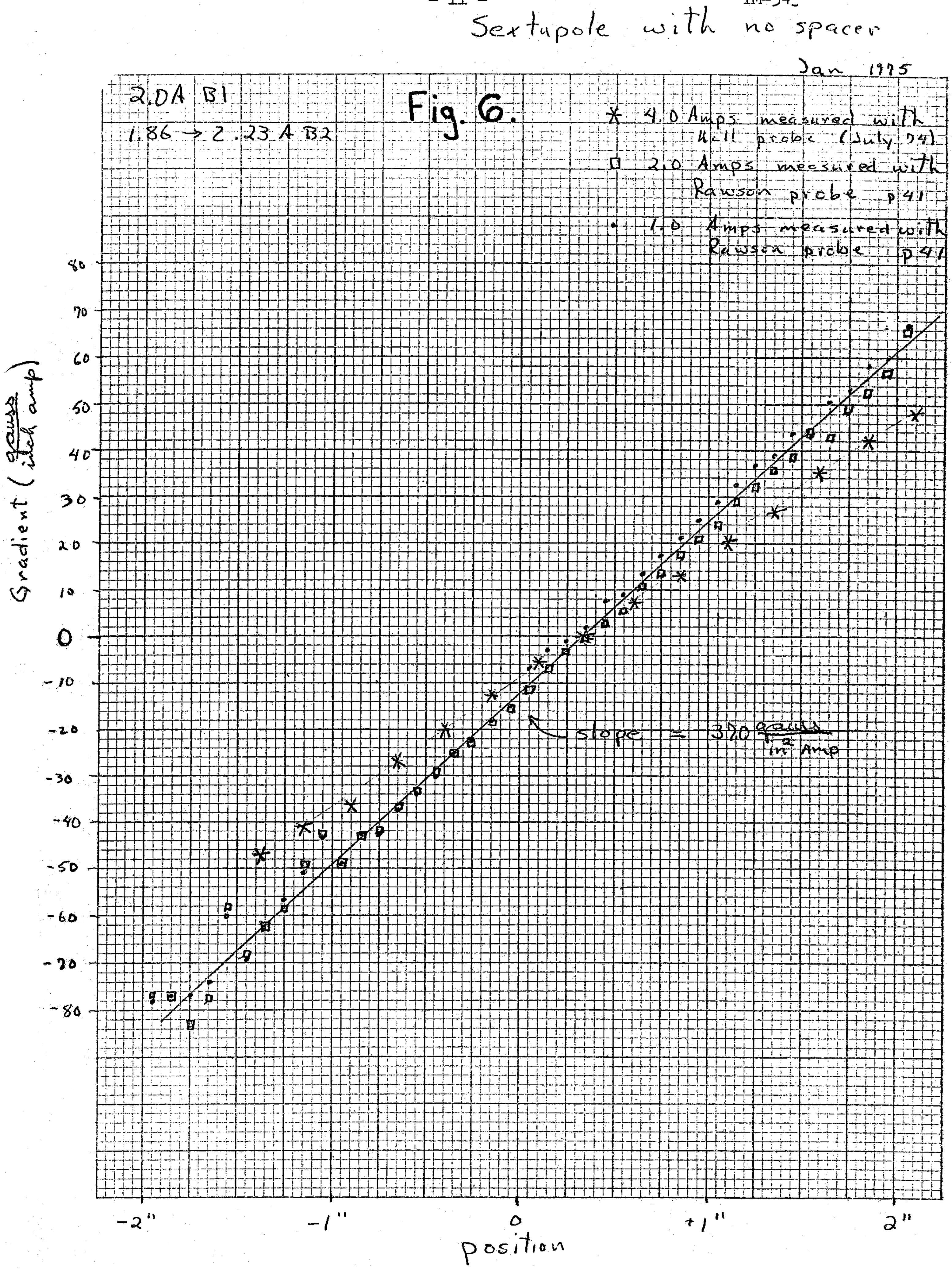
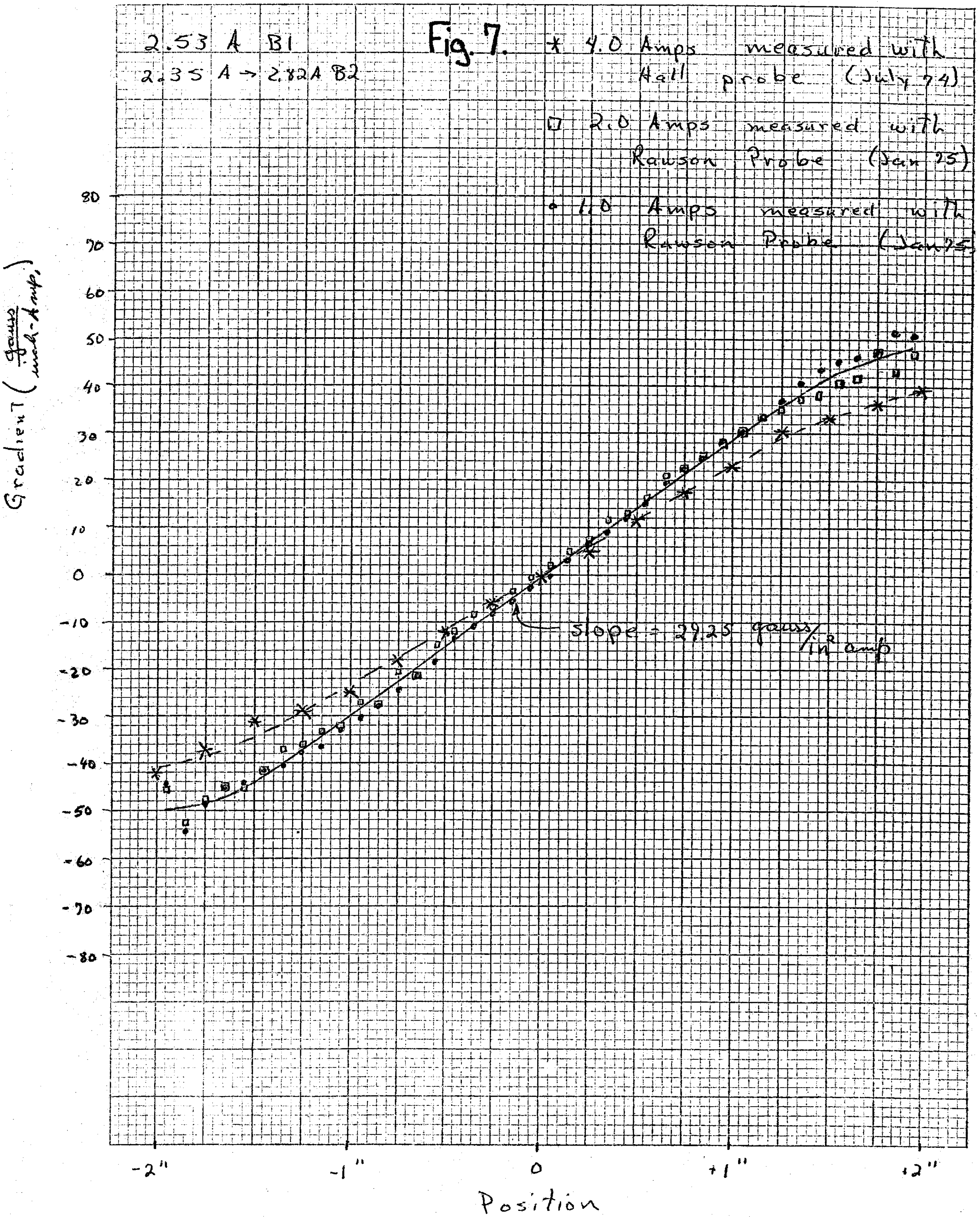


Fig. 5
B2 Data
P-56 #57
slope = 408 gauss/in
1.5
1.0
0.5
0
-0.5
-1.0
-1.5
0.5
0
-0.5


Sextupole with no spacer
Jan 1975
2.0A B1
1.86 → 2.23 A B2
Fig. 6.
* 4.0 Amps measured with Hall probe (July 74)
□ 2.0 Amps measured with Rawson probe p 41
• 1.0 Amps measured with Rawson probe p 41
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
Gradient (gauss / inch amp)
slope = 370 gauss / in² Amp
-2"
-1"
0
+1"
2"
position

Sextupole with $\frac{1}{4}$ inch G-10 spacer



Sextupole with $\frac{1}{2}$ inch G-10 Spacer

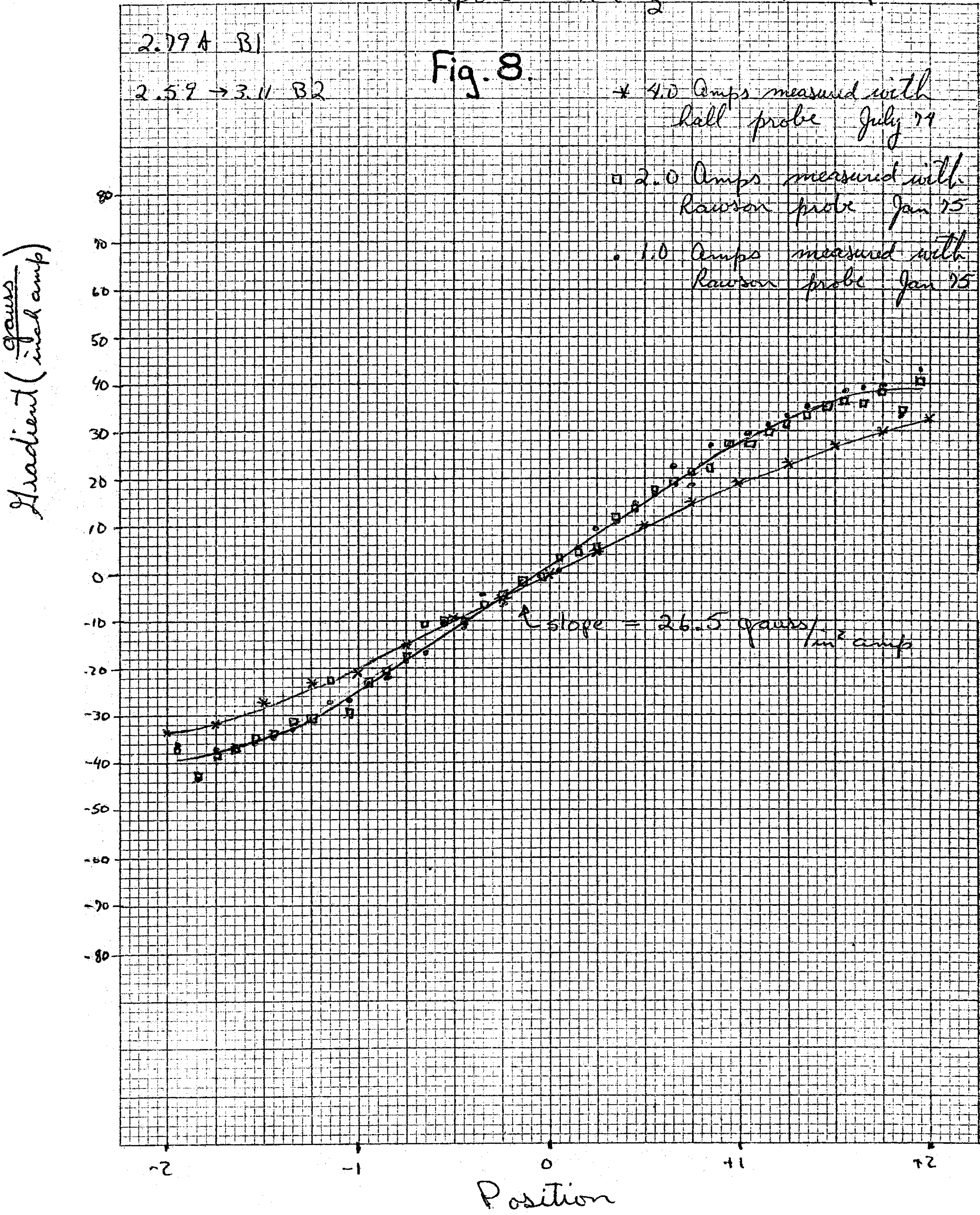
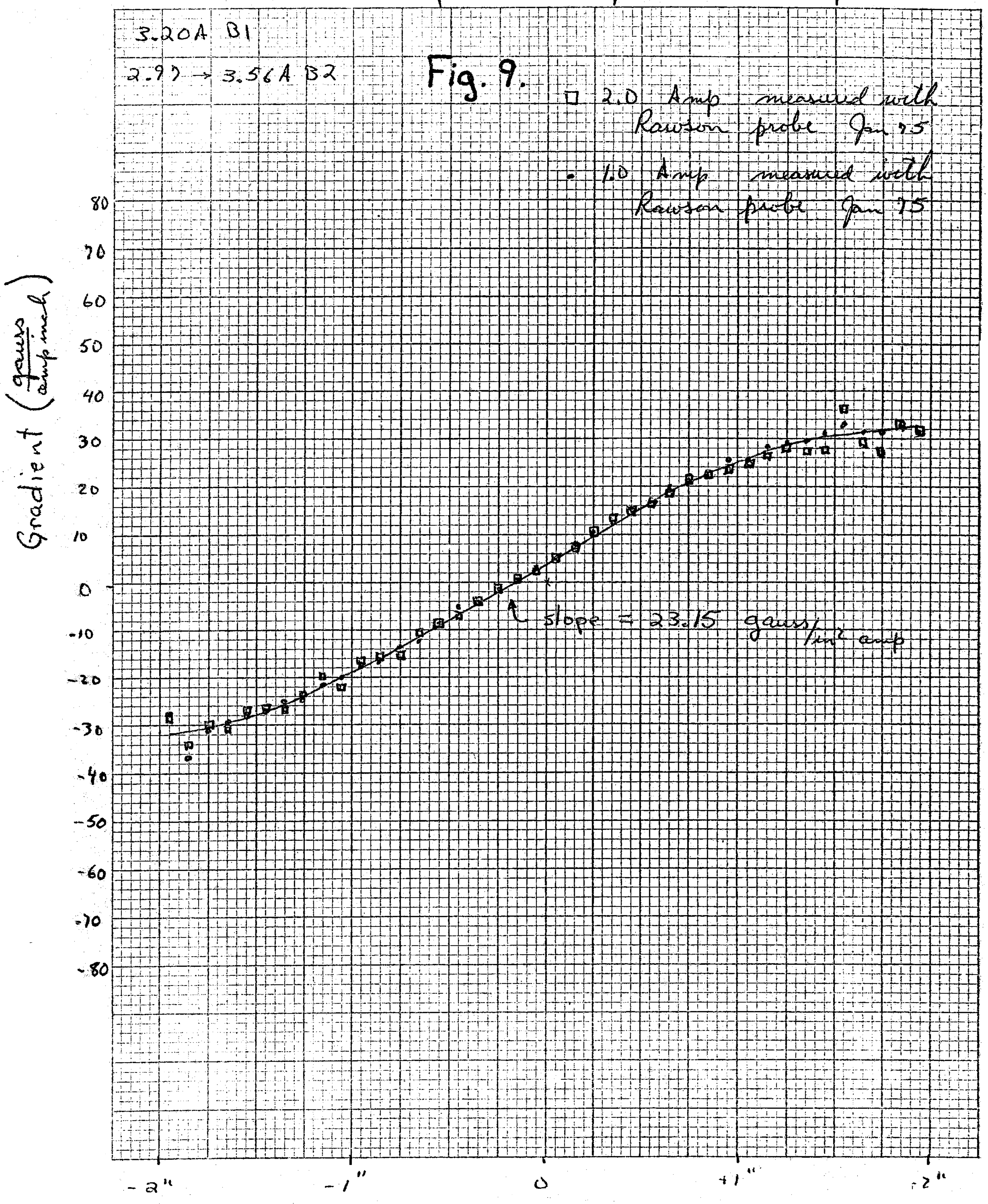
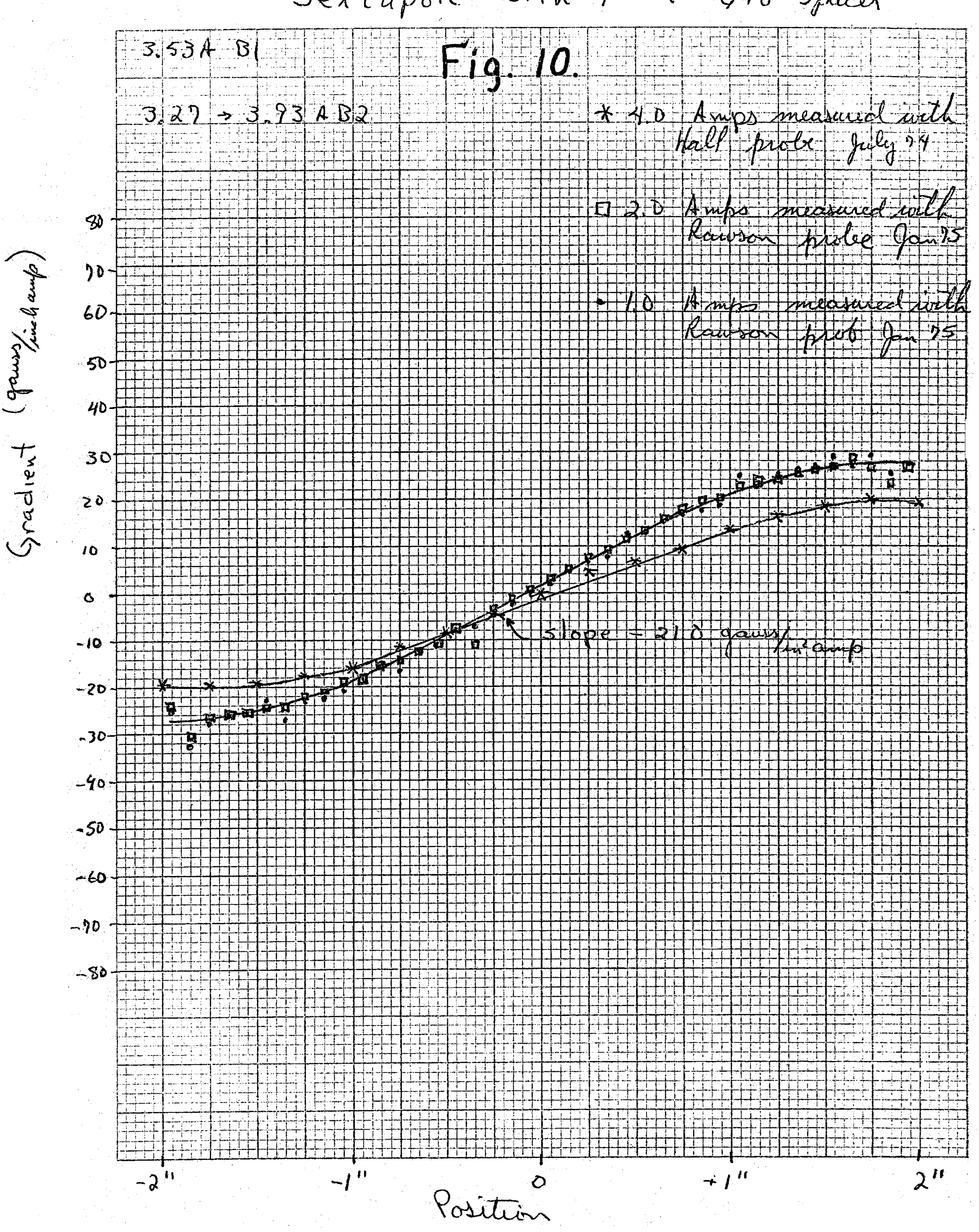


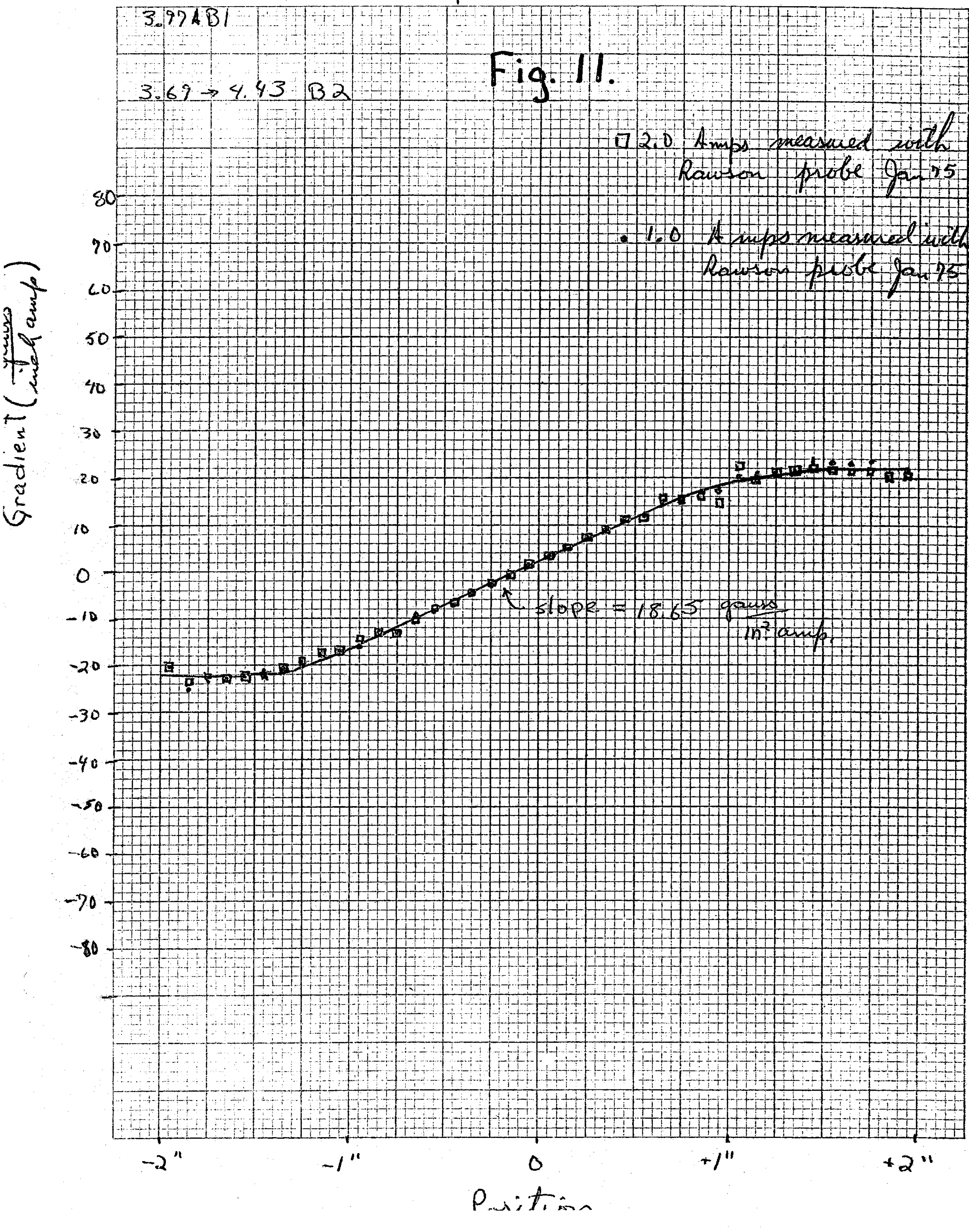
Fig. 8.

Sextupole with $\frac{3}{4}$ inch G-10 Spacer




Sextupole with 1 inch G10 Spacer
3.53A B1
3.27 → 3.93 A B2
Fig. 10.
* 4.0 Amps measured with Hall probe July 74
□ 2.0 Amps measured with Rawson probe Jan 75
• 1.0 Amps measured with Rawson prob Jan 75
slope = 21.0 gauss/in²amp
Gradient (gauss/inch amp)
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-2"
-1"
0
+1"
2"
Position

Sextupole with $1\frac{1}{4}$ inch Spacer



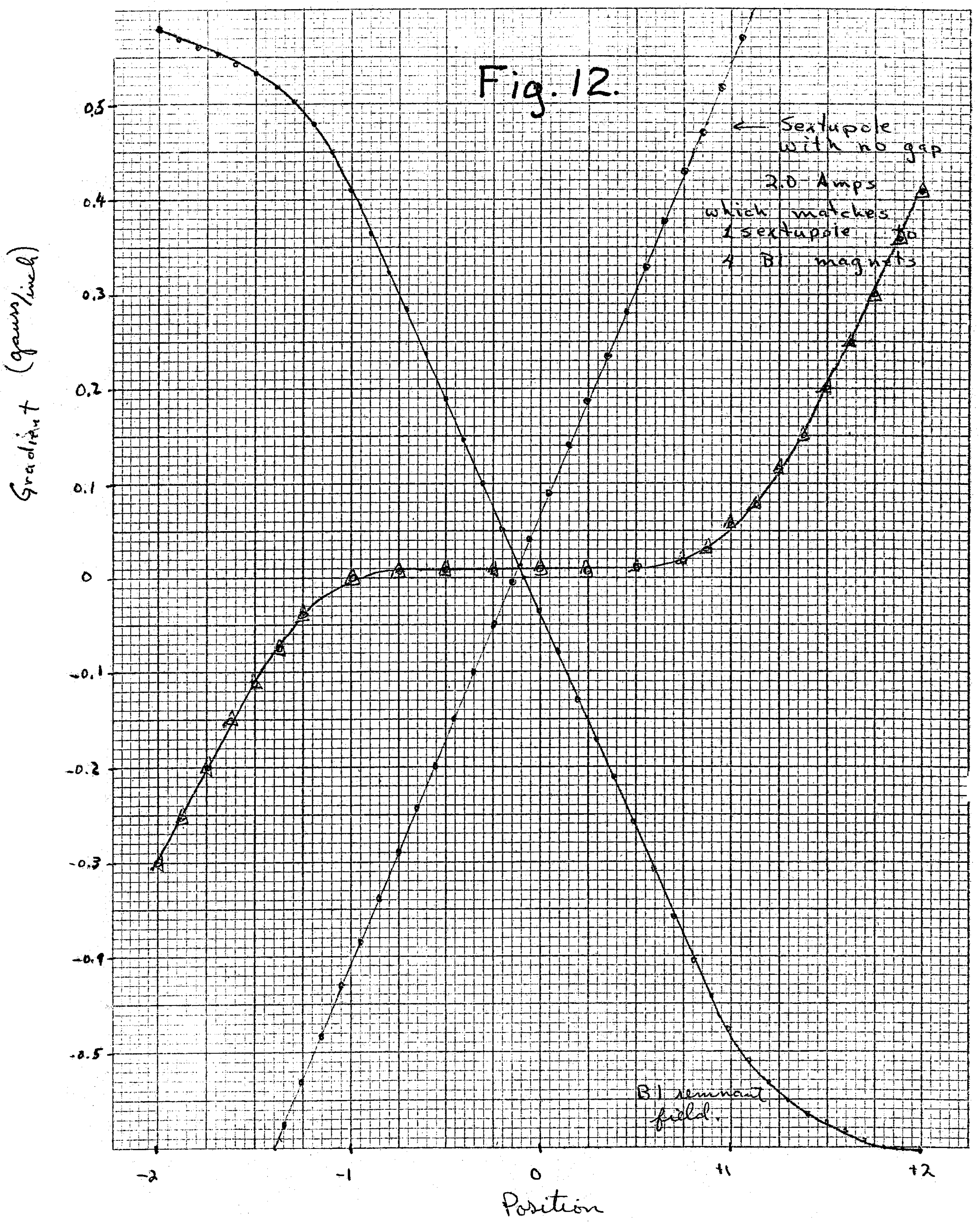
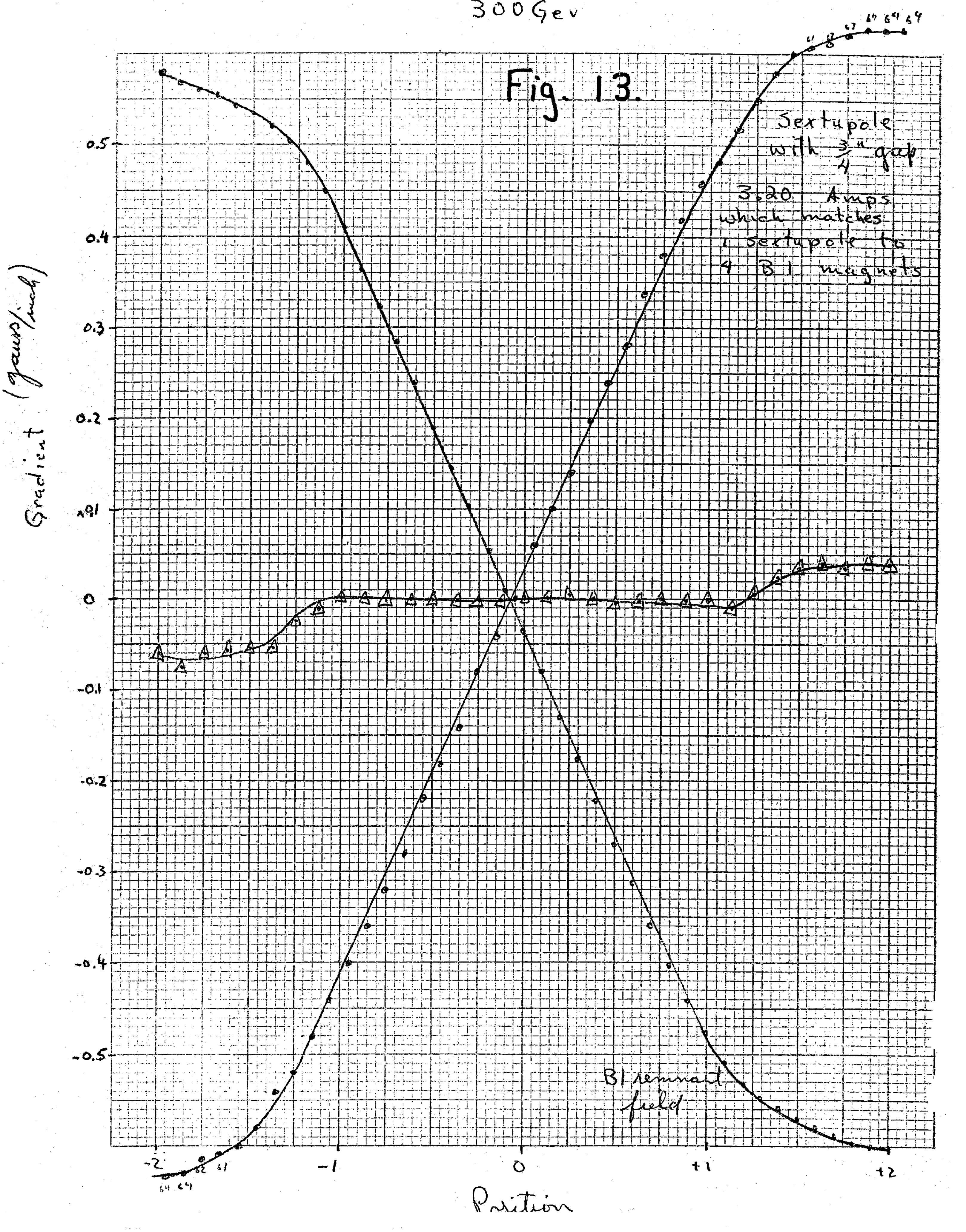


Fig. 12.
← Sextupole with no gap
2.0 Amps
which matches 1 sextupole to 4 B1 magnets
B1 remnant field.
Gradient (gauss/inch)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-2
-1
0
+1
+2
Position


300 Gev
Fig. 13.
Sextupole
with 3/4" gap
3.20 Amps
which matches
1 sextupole to
4 B1 magnets
Gradient (gauss/inch)
0.5
0.4
0.3
0.2
.01
0
-0.1
-0.2
-0.3
-0.4
-0.5
-2
-1
0
+1
+2
Position
B1 remnant
field

300 Gev

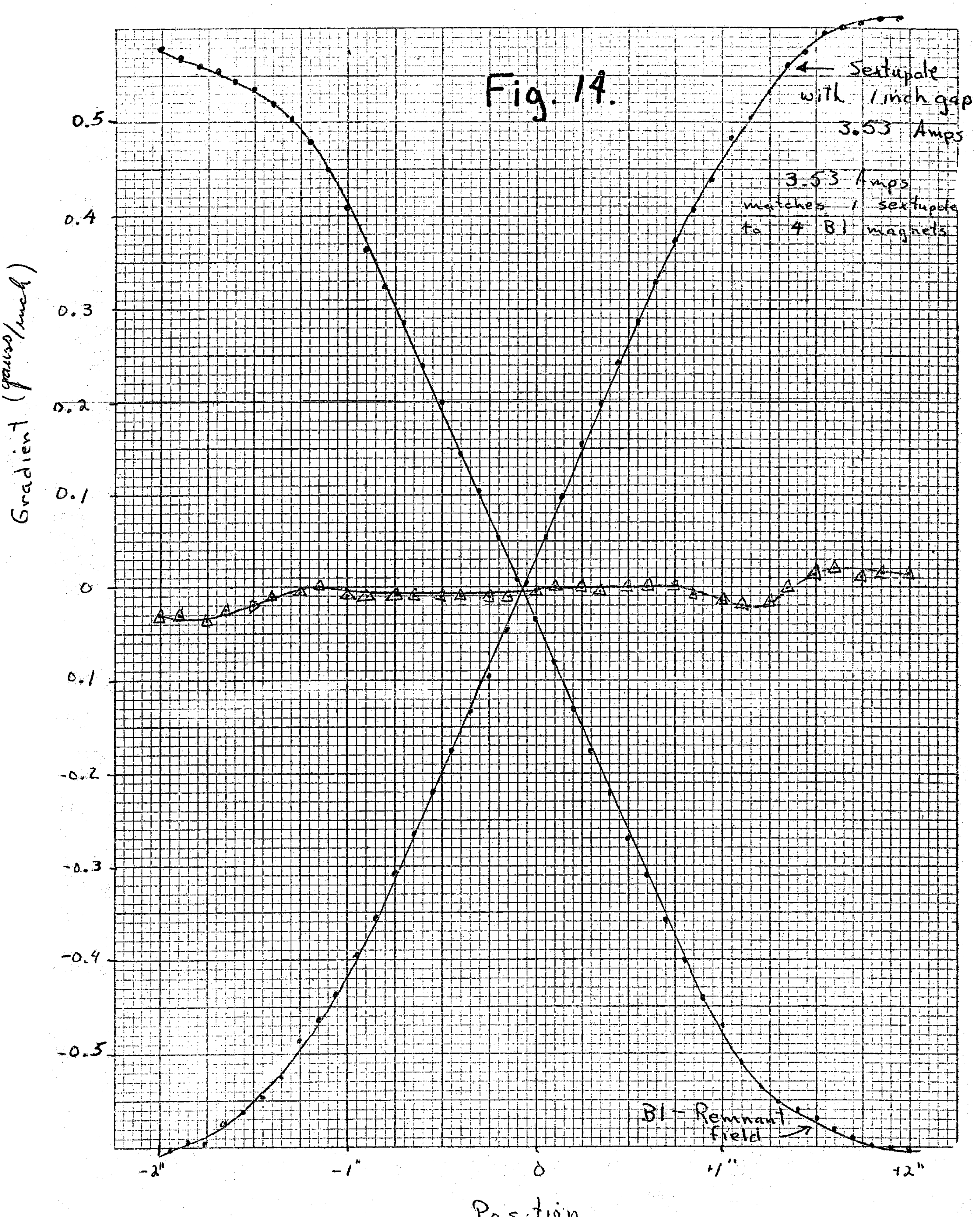


Fig. 14.
Sextupole with 1 inch gap 3.53 Amps
3.53 Amps matches 1 sextupole to 4 B1 magnets
B1 - Remnant field
0.5
0.4
0.3
0.2
0.1
0
0.1
-0.2
-0.3
-0.4
-0.5
Gradient (gauss/inch)
-2"
-1"
0
+1"
+2"
Position

300 Gev

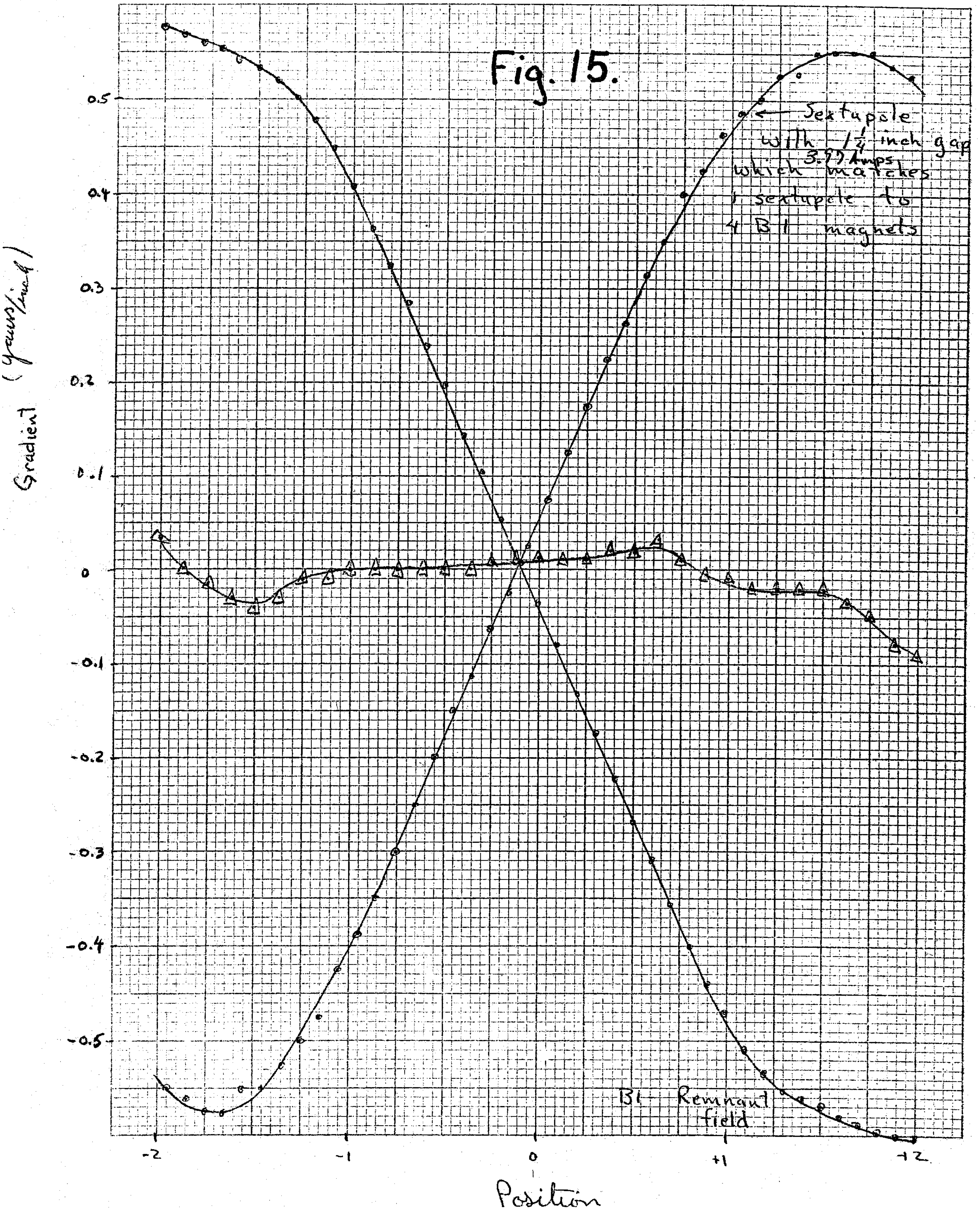


Fig. 15.
Sextupole with $1\frac{1}{4}$ inch gap 3.97 Amps which matches 1 sextupole to 4 B1 magnets
B1 Remnant field
Gradient (gauss/inch)
Position
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-2
-1
0
+1
+2

400 Gev

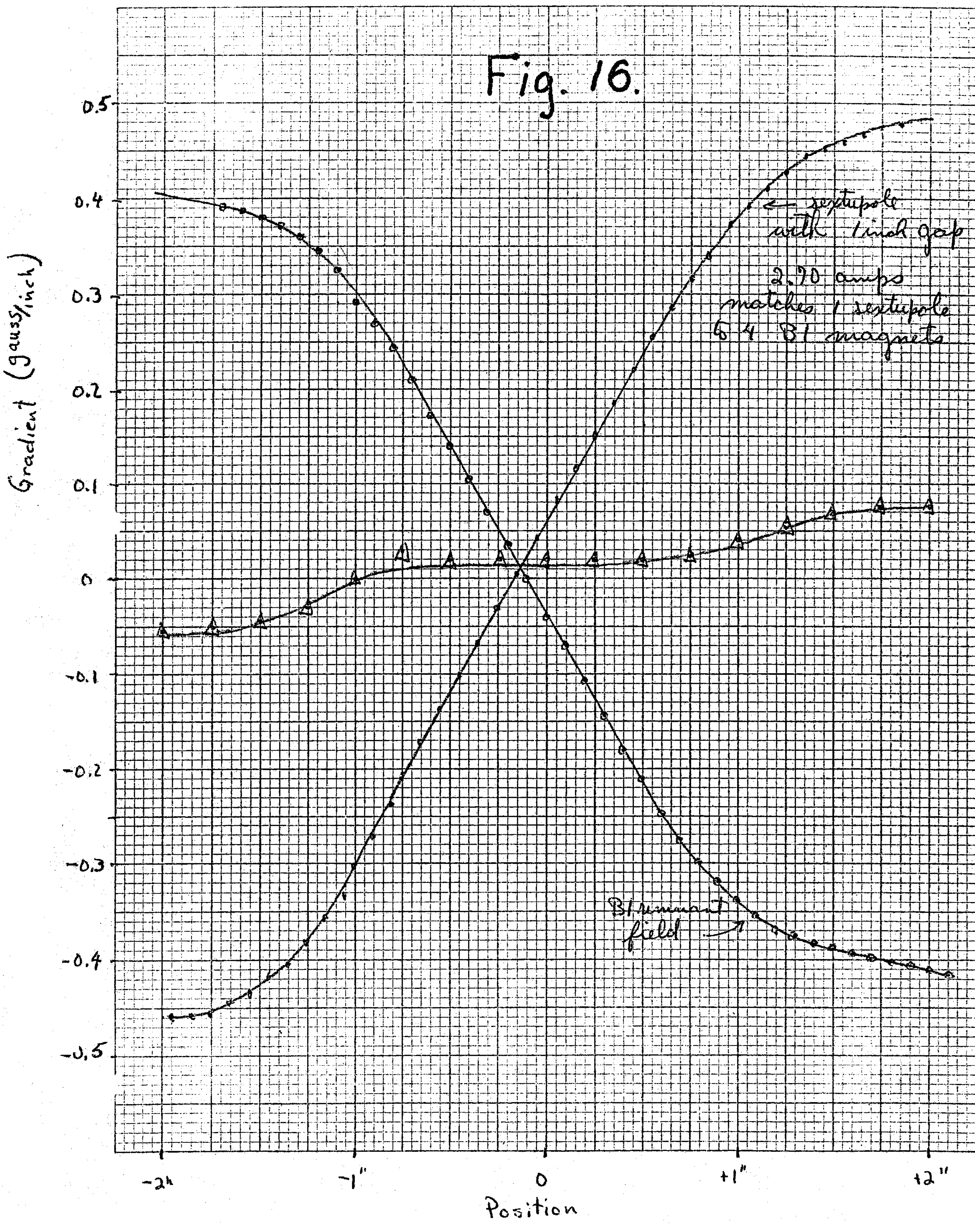
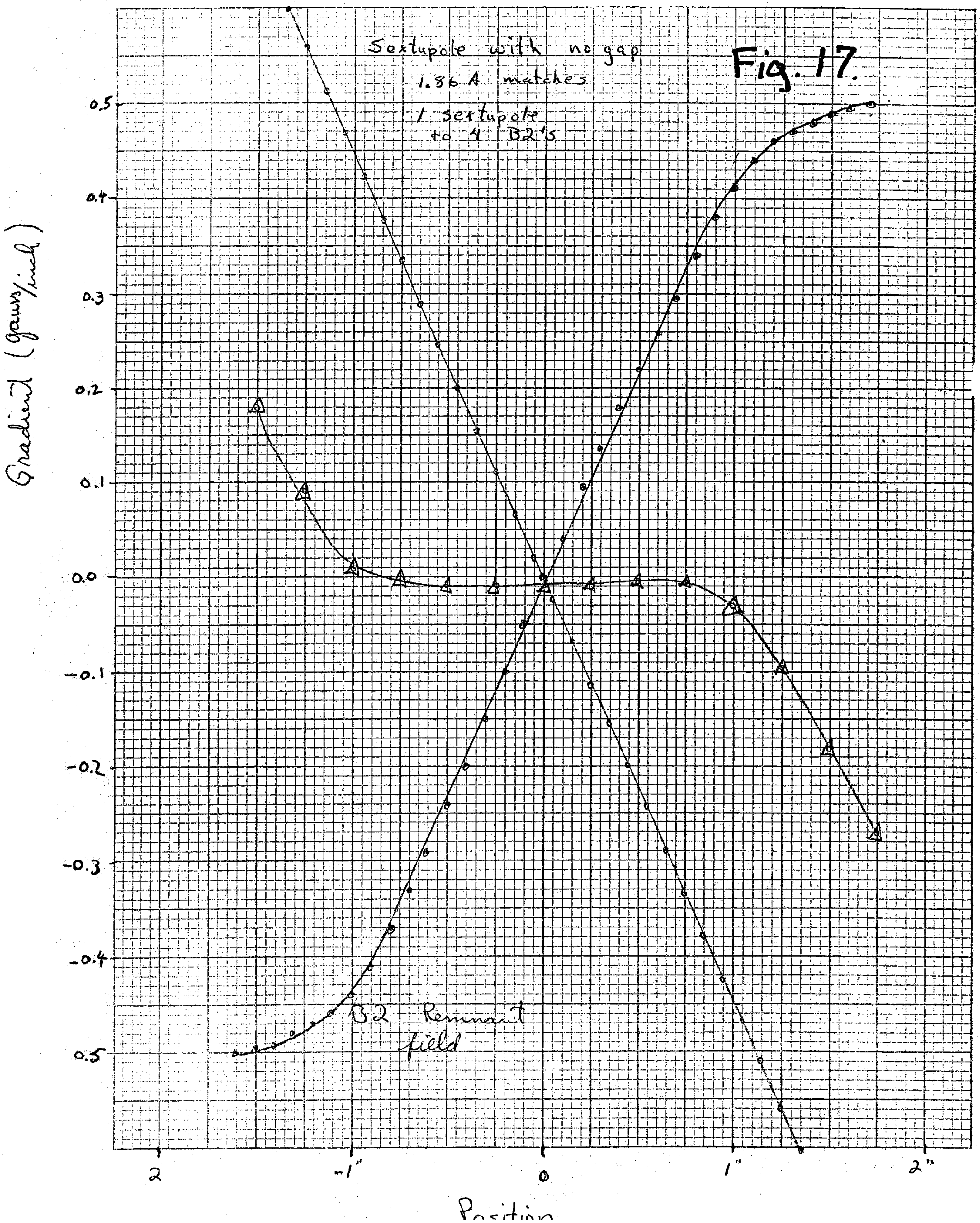


Fig. 16.
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
Gradient (gauss/inch)
sextupole with 1 inch gap
2.70 amps matches 1 sextupole to 4 B1 magnets
B1 remnant field
-2"
-1"
0
+1"
+2"
Position

300 GeV


Sextupole with no gap
1.86 A matches
1 sextupole to 4 B2's
Fig. 17.
B2 Remnant field
Gradient (gauss/inch)
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
0.5
2
-1"
0
1"
2"
Position

300 Gev

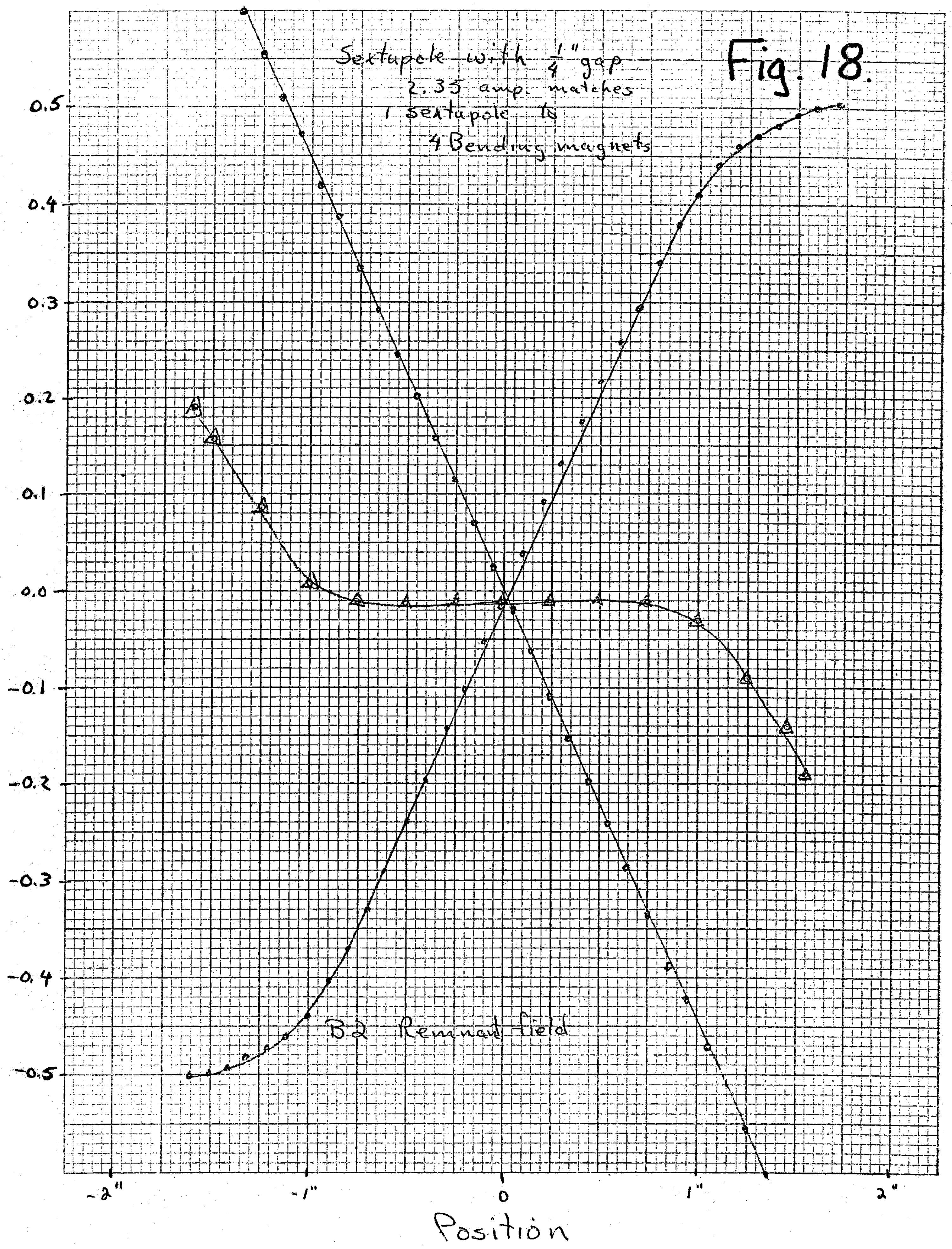


Fig. 18.

400 Gev

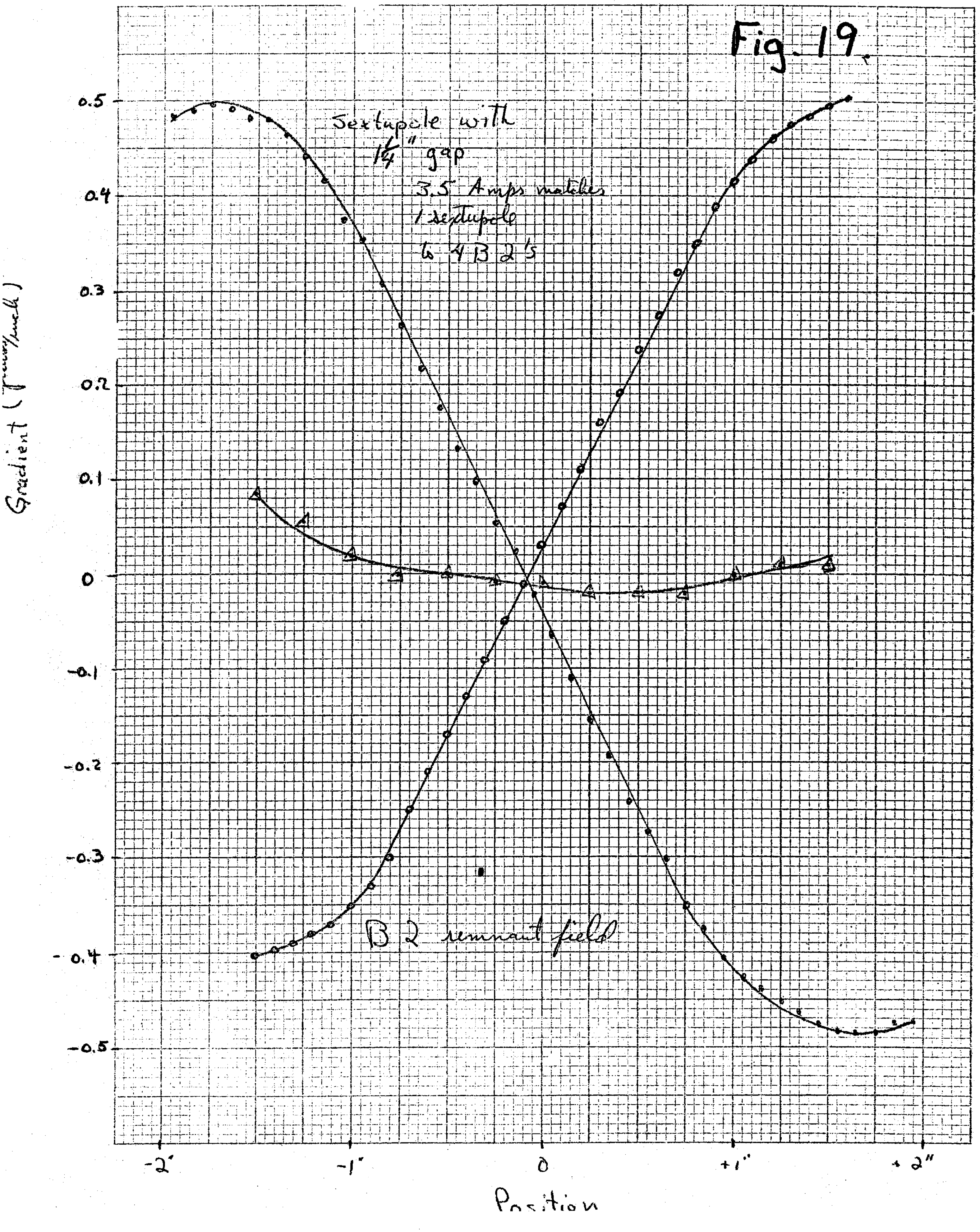


Fig. 19.
Sextupole with
1¼" gap
3.5 Amps matches
1 sextupole
to 4 B 2's
B 2 remnant field
Gradient
Position
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-2"
-1"
0
+1"
+2"